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13. ABSTRACT (*Maximum 200 words*)

Over the two years of the ASSERT grant and the 3 years of the parent grant, the students supported by the grants performed studies that greatly extended our knowledge about the importance of working memory capacity in the performance of cognitive tasks and clarified the nature of the causes of individual differences in working memory capacity. One set of studies showed that working memory capacity was important in the suppression of distracting information. Individuals with greater working memory resources are better able to block and inhibit both distracting events from the environment and thoughts that interfere with ongoing processing. This places even greater importance on the evaluation of individual differences in working memory for jobs in which distractions could impede performance. The final project on the grants was a large factor analysis of working memory tasks, short-term memory tasks, general fluid intelligence tests and Verbal and Quantitative Scholastic Aptitude Tests. The analysis clearly demonstrated that a wide variety of so-called working memory tasks reflect a common latent trait and that the trait is very closely related to both general fluid intelligence and to aptitude as measured

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by the SAT's. If the renewal of these grants is funded, my lab will pursue the role of attention switching and task switching in working memory capacity and the relationship between many findings from my lab over the years and findings with patients with damage to the prefrontal cortex of the brain. This would suggest that individual differences in working memory capacity reflects differences in functioning of the central attentional system in general and the prefrontal cortex in particular.

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F49620-94-1-0257
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Final Report

Annual Technical Report for

AASERT Grant

AIR FORCE OFFICE OF

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This grant funded two graduate students to work on projects exploring the nature of individual differences in working memory capacity and what those differences mean for aspects of real-world cognition. The two students were involved in a wide variety of projects in the lab, finished their MA and have gone on to pursue the Ph.D. In addition to the two graduate students, 12-15 undergraduates were involved in the grant over the funding period and some of them were paid from the grant. Several of those have gone on to pursue graduate degrees in psychology.

The first year of the AASERT grant was spent on three series of studies. One series of studies was directed at whether the ability to inhibit irrelevant information is attention demanding and whether that ability is related to individual differences in working memory capacity. We chose as a model of cognitive inhibition the negative priming effect which occurs when subjects name a red letter which is along side a green distractor letter. If the distractor on trial n becomes the named letter on trial n+1, the subject is slower to name the target letter presumably because it had been inhibited on the previous trial. We conducted three studies which showed that the negative priming effect is eliminated when subjects perform the task under a memory load regardless of whether the load is based on recall or recognition of irrelevant words presented among the naming trials or recognition of abstract visual shapes.

Further, low working memory capacity subjects do not show negative priming even under no load conditions. A paper reporting one of the studies was published in Psychological Science and another paper reporting the other two studies is currently being reviewed.

The second series of studies followed up our earlier work showing that working memory capacity plays a role in retrieval only under conditions of interference. Two studies showed that this generalization holds for retrieval of well learned information when the fan of interfering information was manipulated. In the absence of overlap in fan membership, there was no difference in the retrieval functions of high and low span subjects. When there was overlap, a condition which we thought provided a state of response competition or interference, the high span subjects performed just as they had in the no interference condition. However, the low span subjects showed markedly slowed retrieval functions under interference conditions. This is a pattern of results that we have observed in numerous other situations in our lab, namely, no difference in the performance of high and low working memory subjects under conditions in which do not force or encourage controlled attention but large differences when the task demands or reinforces the use of controlled attention.

The students performed another series of two studies which showed that high and low working memory subjects both performed as

instructed and used a mental model stragegy in a Johnson-Laird classification task. While the high span subjects changed strategies over trials as the mental model strategy proved undesirable, the low spans subjects maintained that approach even when it was no longer rational.

This past year, there were two major projects completed on the grant. One of the projects was a large scale factor analysis designed to answer several questions about working memory, short-term memory, reading comprehension as defined by the Verbal Scholastic Aptitude and general intelligence. The questions included: (1) Do the variety of tasks purported to be working memory tasks all reflect the same construct? (2) Do WM tasks and STM tasks reflect the same or different constructs? (3) What is the relationship among WM, STM and reading comprehension? (4) What is the relationship among WM, STM and general fluid intelligence? The tasks are described in some detail below.

1. <u>Operation Word Span (OSPAN):</u> Subjects were presented with a series of math-word combinations such as "Is (6 x 1) - 1 = 11? DOG". The subject's task was to solve the math problem (by deciding if the given answer was correct or not) while remembering the unrelated words. After 2-6 math-word combinations, subjects were given a recall cue (???) and were asked to recall the words in their correct order. Recall was

scored as correct only the words were recalled in their correct serial order.

2. Reading Span (RSPAN): This task is very similar methodologically to OSPAN, with one important difference. In RSPAN, subjects were presented with *sentences*, followed by unrelated words (e.g., The name of the USC mascot is Cocky. HOUSE). Following word recall, subjects were given comprehension questions to make sure they were paying attention to the sentences. Word recall was scored as correct only the words were recalled in their correct serial order.

3. Counting Span (CSPAN): In this task, subjects were presented with displays which contained dark blue circles, light blue circles and dark blue squares. During each display, subjects counted the number of dark blue circles. After 2-8 displays, subjects were given a cue (???) which indicated that they had to recall the number of dark blue circles from each previous display. Recall was scored as correct only when the number of dark blue circles from each display was recalled in the correct order. For example, if the number of dark blue circles on trial n was 1, the number on trial n + 1 was 6 and the number on trial n + 2 was 4, the correct recall would be 1, 6, 4.

4. Keeping Track (KTRACK): In this task, subjects were presented with 15 words on each trial, and were asked to recall the last exemplar of (1-6) categories. The critical categories were presented to the subject before

and during word presentation. For example, if the categories ANIMALS and COLORS were presented before the list, the only words the subject had to recall were the *last* exemplar from each category (each category could have 1-5 exemplars per trial). Order of recall was not considered when scoring KTRACK data.

5. ABCD: In this task taken from the CAM4, subjects were presented with 3 propositions describing the relative positions of 4 objects (e.g., The furniture is to the left of the animals; The dog is to the left of the cat; The table is to the right of the chair). Each proposition was presented for 3 seconds. Following the offset of the final proposition, 8 alternatives were presented to the subject (e.g., dog cat chair table). The subject's task was to choose the alternative that is consistent with all three descriptions. ABCD is scored as percentage correct.

6. Continuous Opposites (CONTOP): In this task taken from the CAM4, subjects were presented with 3 - 8 words. The words were presented on the monitor, and appear in red or white type. If a word was presented in white, subjects were supposed to remember that word. If a word was presented in red, they were supposed to remember the opposite of that word. When given the recall cue, subjects recalled the last three words (or their opposites) that were presented to them.

7. Immediate Free Recall (IFR): In this task, subjects were presented with 12 words on each trial. The words were presented visually, but the

subjects read them aloud. When given the recall cue (???), subjects were asked to write down as many words as they could remember. Two scores were derived from these data:

(IFR-PM)- immediate free recall primary memory: words recalled with 7 or fewer intervening words between presentation and recall were scored as IFRPM. The IFRPM score is the average number of these words.

(IFR-SM)- immediate free recall secondary memory: words recalled with 8 or more intervening words between presentation and recall were scored as IFRSM. The IFRSM score is the average number of these words.

8. Random Generation: In this task, subjects were asked to randomly generate numbers (1-9) at the rate of 1 number every second. The task was performed in the following way: subjects heard a high pitched tone (from a tape recorder) at the rate of one tone per second. They were instructed to randomly generate a single digit for each tone. As the subject said the digits, an experimenter keyed the digits into the computer for later analysis. The random generation was a measure of the degree of randomness in each subject's output.

9. Forward Span Dissimilar (FSPAND): In this task, 2 - 7 words were presented at the rate of one word per second. Subject's read aloud each word as it was presented. Following the final word, a recall cue (???) was

given to the subject, at which point they recalled the words from the previous trial. Recall was scored correct only if the words were recalled in the correct serial order.

10. Forward Span Similar (FSPANS): This task was nearly identical to FSPAND with one exception: In FSPANS, on each trial, all the words rhymed (e.g., DOG, BOG, HOG).

11. Backward Span (BSPAN): This task was also similar to FSPAND with one exception. In BSPAN, subjects were asked to recall the word in the reverse order that they were presented. For example, if the subject was presented with DOG, CHAIR, HOUSE, the correct recall would be HOUSE, CHAIR, DOG.

12. Raven's Progressive Matrices Test - a non-verbal test of general fluid intelligence.

13. Cattell Culture Fair Test - a non-verbal test of general fluid intelligence.

14. Verbal and Quantitative Scholastic Aptitude Test - Two components of a widely used and highly standardized aptitude test. The VSAT is commonly used as a wide-range reading comprehension test.

All tasks were administered to 133 subjects who were tested individually in 3 different sessions. An initial exploratory factor analysis was performed on the scores from the memory tasks to determine whether WM and STM could be fit with a single factor. A single factor

solution was not adequate. Further, not only did a two factor solution fit, it was significanly better than the single factor solution. Interestingly, the Random Generation task did not load with either factor and forcing into the the factor analysis led to it loading on its own factor.

Next, a series of comfirmatory factor analyses was performed. We used the tasks that appeared to be our best WM tasks (OSPAN, CSPAN, & RSPAN) and the 3 tasks that appeared to be our best STM tasks (FSPANS, FSPAND, & BSPAN). Again, a single factor was unacceptable with an AGFI of .81. A two factor solution led to an AGFI of .93, and more importantly, the two factor solution was significantly better than the one factor solution.

The next step was to examine how well all memory tasks would fit into a two-factor solution. The highest reasonable AGFI (.91) was obtained when the WM factor included OSPAN, CSPAN, RSPAN, Keeping Track, IFR-SM, and the two CAM4 tasks, ABCD and Continuous Opposites. The STM factor included FSPAND, FSPANS, and BSPAN. The IFR-PM score had to be dropped from the analysis because it led to an overall AGFI that was below .9. Thus, the answer to the first of our questions is that nearly all of the tasks that have been used in the literature as WM tasks all load on the same factor. There was a relatively small range of loadings across the 7 WM tasks. The one exception was the Random Generation task used by Baddeley (1996). This task did not

fit with any of the other WM or STM tasks and repeatedly wanted to load by itself.

The second question was whether WM and STM tasks reflected the same construct. This was answered by the fact that the WM and STM tasks forced a two factor solution. This was further spoken to by the relationship of WM and STM factors, respectively, to VSAT and to the general fluid intelligence measures. A regression analysis using the factor scores for WM and STM showed that the correlation between WM and the gF factor (Raven's & Cattell) was .51 and when the STM factor was partialled from the WM-gF relationship it was not substantially reduced (.47). The STM-gF relationship was small (.244) and when WM was partialled out of the relationship it became non-significant. Stepwise regression showed that WM accounted for 26.4% of gF variance but STM did not add a significant amount accounted for.

One common finding in my lab is that simple word span and the complex WM tasks such as OSPAN equally correlate with VSAT. The present analysis showed the same thing. The WM factor correlated with VSAT .58 and the STM factor correlated with VSAT .51. Regression analysis showed that controlling for either factor left a significant relationship with the other and VSAT. In other words, STM does not appear to be that important to general fluid intelligence but it does appear to contribute unique variance to VSAT.

The second project on the grant this year also represented a major investment in time and resources. However, unlike the factor analysis, this project does not appear to have provided any interesting results. The purpose of this project was to determine whether high and low WM subjects would show differences on different aspects of the Stroop task. Eighty subjects, half high WM and half low WM, were tested on 720 Stroop trials. Half of the trials were under bright color conditions and half were under dull color conditions. It was assumed that more attention would be necessary to do the task under dull conditions and that low WM subjects would suffer disproportionately. Further, there were three trial type conditions: (1) Neutral, non-color words printed in color and the subject had to name the color of the ink, (2) Incongruent, color words printed in color and the subject was to name the ink, and (3) Congruent, color words printed in ink of the same name as the word. While low span subjects were generally slowed by the dull condition, there was no interaction between span group and trial type so high and low WM subjects did not perform significantly differently for Neutral, Incongruent and Congruent trials.

The work from the lab, including the work done by the two students funded by this AASERT grant, has increased our understanding of what has been referred to as working memory capacity. It is now clear that individual differences in working memory capacity corresponds to

differential ability to bring controlled attention to bear on processing in situations involving: (1) maintenance of a representation necessary for later processing, (2) suppression of a representation that would interfer or distract from processing, (3) monitoring output of automatic activation to prevent error, (4) controlled, planful search during retrieval, (5) conflict among schemas competing for action. A special case of this last function is scheduling of contending schemas for action or what Shallice and Burgess (1993) called contention scheduling. The work by the two students funded by this grant was instrumental in the development of these conclusions.

These two students each completed a thesis during the grant period and both of them chose to remain at the University of South Carolina when the PI moved to Georgia Tech.

PERSONNEL ON THE GRANT:

Stephen Tuholski, Thesis title - Individual differences in the fan effect: The effect of interference.

Rebecca Shisler, Thesis title - An analysis of individual differences in the Stroop task.

PAPERS RESULTING FROM THIS GRANT:

1. Engle, R.W., Conway, A.R.A., Tuholski, S.W., & Shisler, R.J. (1995). A resource account of inhibition. *Psychological Science, 6,* 122-125.

3. Tuholski, S.W. & Engle, R.W. Mental models: Now you see them, now you don't. (submitted to *Memory & Cognition.*)

4. Shisler, R.J., Conway, A.R.A., Tuholski, S.W., & Engle, R.W. Attentional resources and inhibition: The effects of mental load on negative priming. (Submitted to *Perception and Psychophysics.*)

5. Tuholski, S.W., Laughlin, J., Conway, A.R.A., & Engle, R.W. An analysis of working memory and short-term memory tasks and their relationship to higher level functions. (In preparation for *Journal of Experimental Psychology: General*).